CHAPTER 2

OBJECTIVES AND PRINCIPLES OF WATER CONTROL MANAGEMENT

2-1. General Considerations

a. Introduction

(1) This chapter provides a summary of water control management objectives and principles for various types of water control systems. It presents a brief synopsis of the technical aspects of each of the specific water control requirements to achieve the water management goals set forth below. The discussions present only broad aspects of each water regulation function, and their interrelationship needed for developing a water control plan.

(2) The sections that follow in this chapter discuss the individual functional objectives and principles in water management to achieve flood control, navigation, hydroelectric power, water supply (irrigation, municipal and industrial), water quality, and the preservation or enhancement of fish and wildlife, and recreational use. The discussions provide background information for more detailed presentations in subsequent chapters on methods of developing water control plans and scheduling water releases.

b. Water Management Goals and Objectives. The policy contained in Paragraph 6 of ER 1110-2-240 defines the goals and objectives for water regulation by the Corps. In summary, the objective is to conform with specific provisions of project-authorizing legislation and water management criteria defined in Corps of Engineers reports prepared in the planning and design of a particular project or system. Beyond this, the goals for water management will include provisions as set forth in any applicable authorities established after project construction and all applicable Congressional Acts relating to operations of Federal facilities (for example, the Fish and Wildlife Coordination Act, PL 85-624; Federal Water Project Regulation Act - Uniform Policies, PL 85-624; National Environmental Policy Act of 1969, PL 91-190; and Clean Water Act of 1977, PL 95-217). A general prime requirement in project regulation is the safety of users of the facilities and the general public, both at projects and downstream locations. The development of water control plans and the scheduling of releases at projects will be coordinated with appropriate agencies or entities (international, Federal, state or local), as necessary to meet commitments made in planning or design. Another goal in water management is to adjust water control plans, whenever possible, to account for changing local conditions.

c. Single Purpose Project Regulation

(1) General. In some cases, reservoirs are authorized for a single purpose and their operation must be for attainment of the authorized purpose. However, the method of operation can often be flexible and this flexibility can produce significant benefits over and above the authorized objective. The operation must be tuned to produce the benefits for environmental and social goals such as flood control, instream quality, in-lake quality, recreation, power, or any other attainable goals the project can achieve without compromising the authorized project purpose.

(2) Reservoirs with Uncontrolled Outlet Works

(a) Some reservoirs have been constructed with uncontrolled outlets. Outflow is dependent on conditions of natural inflow, and storage. With no provision for regulation by operating gates, the induced storage results from restricted capacity of the outlet. That is, the project operates entirely under "free flow" conditions. While this type of project provides a consistent, well defined control, it does not allow for changed conditions or provisions for multipurpose objectives.

(b) While it is unnecessary to prepare detailed regulation schedules for this type of project, it is necessary to define the uncontrolled operation and prepare water control documents to show its effect on downstream control and its relationship to other projects in the system.

d. Multipurpose Project Regulation. More than one water management goal or objective can be accommodated in a water control plan, and reservoir storage may be utilized compatibly for several purposes. The degree of compatibility for each of the water uses depends upon the characteristics of the river system, water use requirements, and the ability to forecast runoff. Either a single reservoir or a system of reservoirs may be regulated in a manner to insure the proper use of storage space. Water levels in impoundments may be controlled to provide sufficient storage space to control floods, as well as to store water for hydroelectric power, irrigation, navigation, municipal or industrial water supply use, water quality, propagation and preservation of fish and wildlife, recreation, and aesthetic purposes. Water levels in reservoirs and in rivers downstream from projects may also be regulated to achieve the desires and requirements for public use, recreation and to support fish and wildlife needs. The melding of all of the above-mentioned uses is reflected in the water control plan. In many cases, the uses are somewhat conflicting, and some degree of compromise is required to achieve the water management goals. There is, however, a generally recognized priority for each of the major uses, whereby the defined project benefits are assured to the greatest extent possible. The balancing of water use demands and priorities are defined in the water control plan.

e. System Control. The control of projects to meet water control objectives may be considered for a single river or for a river system consisting of several tributaries, with multiple projects located on the main river or the tributaries. Normally, the control of a multiproject system requires an integrated water control plan whereby projects are regulated jointly in order to achieve the overall river basin management objectives. In such cases a master water control manual is prepared to define system regulation. Where river systems are interconnected hydraulically or electrically, particularly when hydroelectric power is a major operating element, the water control plan may encompass requirements which extend beyond a single river basin boundary and entail regional water or power requirements.

f. Minimum Streamflow. Increasing importance has been attached to the attainment of minimum streamflows during the last several decades as experience has been gained in the management of water resource systems. Specific areas of concern include instream flow requirements, water rights, navigation, hydropower, water quality, water supply, fish and wildlife, recreation, aesthetic considerations, and drought periods. In many cases, minimum streamflow which satisfies some or all of the above areas of concern is defined as a project purpose in the authorizing documents. Some projects, however, have no formal commitment for minimum streamflow due in large part to the lesser importance which was placed on instream flow requirements, water quality, fish and wildlife, recreation, and aesthetic considerations in the early development of some river basin water management systems. Lack of formal commitment does not preclude the responsibility to define and establish minimum streamflow objectives that may be achieved without jeopardizing authorized project purposes. When minimum streamflow goals and objectives are established they should be based on analyses which consider all project and system impacts to attain the best use of a limited resource. In a multiple purpose project or system of projects operation to satisfy one purpose may satisfy other requirements. For example, water released for irrigation may satisfy other instream requirements, given adequate quantity and quality, until diverted from the river.

2-2. Flood Control

a. Historical Background

(1) General. Federal flood control activity took definite form by establishment of the Mississippi River Commission in 1879, with jurisdiction over navigation work and flood control related thereto on the lower Mississippi River. Federal construction of flood control improvements was extended outside the Mississippi Valley for the first time in 1917, when a project for the Sacramento River, CA was authorized. Following the disastrous flood of 1927, the 1928 Flood Control Act authorized a comprehensive plan for control of the Mississippi River and tributaries. The following legislation marked the beginning of Corps construction and responsibility for Federal flood control projects throughout the nation.

(2) 1936 Flood Control Act

(a) Section 1 of this act declared flood control to be a proper Federal activity; that improvements for flood control purposes are in the interest of the general welfare; and that the Federal government should improve or participate in the improvement of navigable waters or their tributaries for flood control "if the benefits to whomsoever they may accrue are in excess of the estimated costs, and if the lives and social security of people are otherwise adversely affected" (49 Stat. 1570, 33 U.S.C. 701a).

(b) Section 2 set forth the jurisdiction of Federal activities and prescribed among other things, "That, hereafter, Federal investigations and improvements of rivers and other waterways for flood control and allied purposes shall be under the jurisdiction of and shall be prosecuted by the Army Department under direction of the Secretary of Army and supervision of the Chief of Engineers" (49 Stat. 1570, 33 U.S.C. 701b).

(c) Section 3 stipulated for the projects authorized therein what have become known as the "a-b-c" requirements of local cooperation; that local interests should: (a) provide without cost to the United States all lands, easements, and rights-of-way necessary for the construction of the project, except as otherwise provided herein; (b) hold and save the United States free from damages due to the construction works; (c) maintain and operate all the works after completion in accordance with regulations prescribed by the Secretary of Army (49 Stat. 1571, 33 U.S.C. 701c). Requirement (b) was amended by Sec. 9 of the Water Resources Development Act of 1974 (Pub. Law 93-251).

(3) 1944 Flood Control Act. Section 7 of this act specified that the Secretary of the Army shall prescribe regulations for the use of storage allocated for flood control or navigation at all reservoirs constructed wholly or in part with Federal funds, including those of the Tennessee Valley Authority when the lower Ohio or Mississippi Rivers are in danger of flooding; i.e., this law created a specific requirement for reservoirs that include flood control which is funded, at least in part, by Federal agencies other than the Corps. The act provided for developing flood control plans, allocating project costs to the flood control function, and regulating the projects to assure flood control benefits as determined by the Corps. All Bureau of Reclamation (USBR) projects constructed after (and some prior to) 1944, where flood control is one of the project purposes, are included in the provisions of this act. Projects that come under the authority of this legislation are generally referred to as "Section 7" projects. (58 Stat. 893, 33 U.S.C. 709.)

b. Flood Control Measures. Control of floods by structural remedies, such as reservoirs, levees, drainage systems, channel improvements, etc., has long been a national objective. In recent years nonstructural means, such as flood plain zoning, flood proofing or flood insurance, have been incorporated into overall flood control plans to augment structural control. In the operational phase of all of these measures, the overall objective is to minimize flood damage in a given region. Most structural alternative measures to control floods and alleviate flood damage require specific water control plans of operation based on current hydrometeorological conditions, flood control objectives, and the capabilities of appropriate flood control facilities. Unusually large floods may require flood fight activities or other special measures to meet flood control objectives. Streamflow forecasting is an important element in the management of water during floods, and timely use of flood forecasts provide a means for reducing damage in unprotected areas by evacuating people and moveable goods from flood areas. The management of river systems must integrate the information on all aspects of flood control outlined above in order to best manage the control works. Specific flood control measures and objectives are discussed briefly in the following paragraphs. Types of facilities and their requirements are discussed in Chapter 4.

c. Impoundments. A principal structural remedy for flooding is control of streamflows and river levels by impounding runoff. The planning of reservoirs and other impoundments to meet flood control objectives involves hydrologic studies of historical and hypothetical floods, various alternatives in storage capacities and location, downstream flood control objectives, inflows from uncontrolled drainages below the project, channel capacities, flood damage surveys, cost-benefit determinations, and a general plan of regulation to meet the flood control requirements. These planning studies are used to determine the size and location of impoundments, the degree of protection to be provided and the multipurpose uses of projects. They are based on the overall evaluation of river basin development considering economic, environmental and social values. In the design phase, the project studies are refined, and detailed studies are made to determine design of hydraulic features and the water control plan for the project.

d. Objectives for Reservoir Control of Floods

(1) Reservoirs are seldom designed to provide complete protection against extremely large floods, such as the Standard Project Flood. However, the storage capacity is usually sufficient to reduce flood levels resulting from such an event to moderate levels and to prevent a major flood disaster. Reservoirs are usually capable of storing the entire runoff from minor or moderate flood events. The water control plan defines the basic goal of regulation, relative to control of minor and major floods. Usually a compromise is achieved in the water control plan to best utilize the storage space in reservoirs for control of both major and minor flood events. In special circumstances where reservoir inflows can be forecast several days or weeks in advance (for example, when the runoff occurs from snowmelt), the degree of control for a particular flood event may be determined on the basis of forecasts to best utilize the storage space. Also, the amount of flood control storage space may be varied seasonally when runoff is seasonal, in order to utilize the reservoirs for multipurpose regulation.

(2) One of the problems of reservoir control of floods is the requirement for post flood evacuation of stored water. This may result in long duration of river levels at or near bankfull or minor damage stages at downstream control points. The water control plan must account for this requirement, which may entail a compromise between a rapid evacuation of stored water for assuring control of subsequent flood events, and a slow evacuation to allow downstream river levels to recede below bankfull stages as quickly as possible.

e. Reservoir Systems

(1) A multireservoir system is generally regulated for flood control to provide flood protection both in intervening tributary areas and at downstream main stem damage areas. The extent of reservoir regulation required for protecting these areas depends upon local conditions of flood damage, uncontrolled tributary drainage, reservoir storage capacity, and the volume and time distribution of reservoir inflows. Either the upstream or downstream requirements

may govern the reservoir regulation, and usually the optimum regulation is based on the combination of the two. Reservoir releases are based on the overall objectives to limit the discharges at the control points to predetermined damage levels. The regulation must consider the travel times caused by storage effects in the river system and the local inflows between the reservoir and control points. Since each flood event is caused by a unique set of hydrometeorological conditions, the plan of regulation for a reservoir system for flood control should be based on a specific analysis of that particular flood event. This is most easily achieved by modeling the conditions of runoff and reservoir regulation through computerized simulation techniques and determining the control of streamflows at each project in the simulation, in order to achieve the desired downstream control and meet the water control management objectives at each reservoir.

(2) System control can incorporate the concept of a balanced reservoir regulation, with regard to filling the reservoirs in proportion to each reservoir's flood control capability, while also considering expected residual inflows and storage available. Evacuation of flood water stored in a reservoir system must also be accomplished on a coordinated basis. Each reservoir in the system is drawn down as quickly as possible to provide space for controlling future floods. Water control diagrams containing regulation criteria in the form of guide curves and regulation schedules for individual reservoirs are used as guides to define various amounts of storage space as primary and secondary flood control storage. The objectives for withdrawal of water in the various zones of reservoir storage are determined to minimize the risk of encroaching into the flood control storage and to conserve water for future requirements.

f. Levees

(1) Flood protection of land adjacent to rivers is often accomplished by means of levees. Planning and design of these structures are based on several categories of engineering and economic studies involving: (a) hydrologic studies and economic investigations of floods, local drainage, and flood damages; (b) construction materials, foundations, and alternative structural design studies; (c) design of facilities for interior drainage behind the levees; and (d) cost and benefit evaluations. The river control works may involve channel improvements and bank protection facilities. The degree of protection provided by levees is based on planning and engineering considerations as well as the type of area being protected. Design criteria allow for freeboard above the design water surface elevation to account for uncertainties in computed water levels, settlement of levees, etc., in determining the design height to which the levees are constructed. The amount of

freeboard is also dependent upon the type of area being protected. Levees which protect urban areas are usually designed with a high degree of protection (up to Standard Project Flood, if possible) because of the severe hazard and the potential for loss of life in the event of a levee failure.

(2) While most levee projects do not require day-to-day water management, it is important that managers of water control systems be properly appraised of the status of levee projects in conjunction with the overall control of a water resource system. Particularly in times of major floods, the Water Control Center (WCC) or water management element should be alerted to any signs of weakness in the levee system. The WCC should disseminate overall evaluation of flood hazard areas in conjunction with the regulation of reservoirs or diversion structures. Also, flood fighting activities, which involve special precautions to insure the safety and integrity of levees, require the coordinated efforts of the WCC, Operations Division, Emergency Management and other appropriate organizational elements. The latest forecasts of river levels and anticipated potential of future flooding may be assessed and disseminated to the field forces. In some cases, special requirements are incorporated into the design of levees for placing temporary bulkheads at street or highway crossings, or sandbagging vulnerable locations to insure the continuity of protection by the levees. Inasmuch as this must be accomplished ahead of the flood event, it is essential that actions taken to relay and utilize forecasts of anticipated river levels and flood potentials be coordinated.

g. Combined Impoundment and Levee Systems. Flood protection is provided in many river basins through the combined effects of reservoir, other impoundments and levee systems. The design of combined systems is based on planning and engineering considerations that encompass a complete analysis of river basin development. The degree of protection afforded by either levees or impoundments is often limited by economic or social considerations. The height to which levees can feasibly be built may be limited by foundation conditions, construction material availability, feasible rights-of-way, and overall cost-benefit analysis. Similarly, the degree of protection which can be provided by impoundments is limited by the availability of suitable sites, engineering and economic considerations, and social constraints in project development reservoirs. River basin studies determine how the combined use of impoundments and levees may offer a practical and economic solution for providing flood control. Management of combined systems of this type to achieve water control objectives involve the same principles as outlined in the preceding paragraphs for flood protection by impoundments and levees.

h. Local Protection Projects. The following types of projects, when constructed by the Corps, are usually turned over to local interests for operation and maintenance (O&M) after their completion. Those that are transferred to local interests are subjects to Part 208.10, Title 33, of the Code of Federal Regulations, which stipulates the requirements for O&M but is silent in regard to water control management. If either flood control or navigation is a project purpose, the Corps must prescribe the regulation in this regard, and water control procedures for any other authorized purposes are usually offered. This documentation is in the form of Standing Instructions to the Project Operator for Water Control, which is discussed in Chapter 9.

(1) Interior Drainage Systems

(a) Areas protected by levees often include the requirement for drainage of water resulting from seepage of water through the levees or storm runoff from local uncontrolled inflows which drain into the channels behind and on the protected side of the levees. The design of drainage systems to control this type of flooding is based on use of pumping plants, tide or "flap" gates, or temporary storage of water in low-lying areas or channels which are not subject to flood damage. Adequate channels must be constructed to convey the water to the outlets or control structures. The capacities of the various features are determined from studies of runoff from storm rainfall or seepage that might reasonably occur during flood conditions on the main river for which levee protection is being provided.

(b) The facilities constructed for the control of flooding in interior drainage systems often operate automatically and only require surveillance of physical operation during times of floods. As in the case of levee protection, inspections and maintenance of the facilities are also required for assurance of proper physical operation during times of flood.

(2) Diversion and Bypass Structures

(a) Temporary diversions are often required to accommodate the construction of projects. In some river systems, however, excess flood water or water supply is diverted away from the main river channel by means of a permanent diversion or bypass structure and auxiliary channels for the purpose of reducing flood flows and river levels at main stem damage centers. The permanent structures are usually located in flood plain areas, where river slopes are relatively flat. The control structure is usually located adjacent to the main river channel for diverting water into the auxiliary channels. In many cases these structures are seldom used, or pass only nominal amounts of water. However, in some cases vast amounts of streamflow are diverted during flood periods, moderate amounts during low flow periods, and continuously in rare cases. The diversion of water may be controlled through use of control gates, pumps, or the structure may be designed for uncontrolled operation which depends upon the water level in the main river. The capacity of the structure is determined by engineering studies of desired flood stage reduction and downstream channel capacities in the main river and in the auxiliary channels, in connection with the overall plan of flood control which may involve levees and impoundment projects upstream. The auxiliary channels may be improved to provide the required flow capacity without flooding adjacent areas, or they may be unimproved natural overflow channels. The degree of improvement depends upon the frequency of flooding, land use, and economic factors.

(b) Water control management of diversion and bypass structures is very important in controlling release of water through gated structures. It is critical that the timing and use of the structure for diverting flood flows be determined on the basis of the best forecasts of river flows and flood conditions. In some cases, the auxiliary channels are designed to be used only under maximum flood conditions because of adverse effects of flooding along the auxiliary channels. For this reason, they should be utilized only when design floods are anticipated or other conditions warrant their use. Decisions to use the structures should be based on the most complete basic data and technical evaluations available.

(c) Diversion and bypass structures which have ungated spillways or sluices do not require specific water control decisions, since the flow of water through the structure is determined solely by water levels in the river. It is important, however, to anticipate the time when the facilities will operate in order to provide warnings to the people living along the auxiliary channels and to take other actions as necessary.

(3) Hurricane and Tidal Barriers

(a) These facilities are flood control projects, which provide protection against water levels and surges resulting from hurricanes or severe storms, and are located along the ocean coastlines, across tidal estuaries, or along the perimeter of very large lakes with long fetches. These projects consist of rock-lined earthen dikes and/or concrete walls and control structures that confine the water and thereby prevent flooding which would occur from unusually high water caused by storm surges and wave action. Flooding resulting from such occurrences is usually of short duration, ranging from a few hours to as much as a day or two. Although these barriers are generally designed to provide protection against a rare combination of strong winds and high tides, these are unusual events, and most of the regulation activities at these barriers are associated with intense low pressure systems common to all parts of the country.

(b) The facilities protect low lying areas from inundation and wave action, together with control structures, to permit drainage of interior runoff during nonflood periods. In estuaries a movable barrier (sector, tainter or flap gates) may be incorporated into the design to permit navigation through the structure during normal conditions. During tidal flooding this movable barrier closes off the navigation channel to preserve the integrity of the barrier system as a whole. During this closure the interior runoff is either discharged by pumps through the structure or temporarily stored behind the barrier.

(c) In most cases the Corps retains ownership and control of those elements of the barriers which contain navigation facilities; however, the local communities are usually responsible for the O&M activities for barriers that do not contain navigational features.

(d) The management and control of barrier systems requires a water control plan for regulating the structures, including pumping stations, vehicular gate openings, sewer lines and sea water intakes. Also, in cases where such a system involves protection of an estuary where water levels are affected by rivers or tributaries draining into the estuarine channels, the water control plan may involve the overall management of the river system. Forecasts of controlled or uncontrolled tributary inflows may be an important element in the plan.

2-3. Navigation

a. Historical Background. Historically, improvements of national waterways for navigation was an early concern in water resource development in the United States. The first artificial waterways were built in the northeastern United States in the late 18th century and early 19th century by private developers. Federal involvement became a matter of national policy because of the use of waterways for interstate commerce, as well as national and international trade. Over the past century and a half, the Federal government through the Corps of Engineers has been involved in the improvement for navigation of some 22,000 miles of inland and coastal waterways. Types of navigational improvements include canals, locks, dams and reservoirs; maintained channels and estuaries; bank protection, pile dikes, and other forms of channel stabilization. Making reservoir releases to increase river levels and thereby improve channel depths is another type of navigational improvement.

Specific developments in a particular river may involve several of the above-mentioned methods in providing overall navigational improvements. Although the requirements are related mainly to commercial navigation, there are also navigational needs of the general public for small boat operation and recreational use. Commercial needs range from those of intra-river transportation by small draft barges and tows to deep-draft ocean going vessels for general use.

b. Water for Navigation

(1) General. Problems related to the management of water for navigation use vary widely among river basins and types of developments. Control structures at dams, reservoirs, or other facilities where navigation is one of the project purposes must be regulated to provide required water flows and/or to maintain project navigation depths. Navigational requirements must be integrated with other water uses where developments encompass multipurpose water resource systems. In the regulation of dams and reservoirs, the navigational requirements involve controlling water levels in the reservoirs and at downstream locations and providing the quantity of water necessary for the operation of locks. There also may be navigational constraints in the regulation of dams and reservoirs with regard to rates of change of water surface elevations and outflows. There are numerous special navigational requirements that may involve water control, such as ice, undesirable currents and water flow patterns, emergency precautions, boating events, launchings, etc.

(2) Water Requirements for Lockage and Controlled Canals

(a) Navigation locks located at dams on major rivers generally have sufficient water from instream flows to supply lockage water flow requirements. Navigation requirements for downstream use in open river channels may require large quantities of water, metered out over a long period of time (from several months to a year), to achieve a significant, continuous increase in water levels for boat or barge transportation. Usually, water released from reservoirs for navigation is used jointly for other purposes, such as hydroelectric power, low-flow augmentation, water quality, enhancement of fish life, and recreation. Seasonal or annual water management plans are prepared which define the use of water for navigation. The amount of stored water to be released depends on the conditions of water storage in the reservoir system and downstream requirements or goals for low-flow augmentation, as well as factors related to the all the uses of the water in storage.

(b) Navigational constraints are also important for short-term regulation of projects to meet all requirements. In some rivers, supply of water for lockages is a significant problem, particularly during periods of low flow or droughts. The use of water for lockages is generally given priority over hydropower or irrigation usages. In critical low-water periods, a curtailment of water use for lockages may be instituted by restricting the number of lockages and thereby conserving the utilization of water through a more efficient use of the navigation system. Water requirements for navigation canals are based on lockages and instream flows as necessary to preserve water quality in the canal.

c. Water Releases for Navigation in Open Rivers. Water released from storage reservoirs to increase long-term downstream flows for navigational purposes may be a major factor in a water control plan that is based primarily on the requirements for hydroelectric power. Also, daily fluctuations in outflow resulting from power peaking operations may be constrained by navigational requirements for minimum water levels at downstream locations. These restrictions may apply to both daily and weekly fluctuations in streamflows and water levels and are determined by requirements for navigation, boating, and public use of the waterway.

d. Winter Navigation. Winter navigation poses a special problem for water control management. The goal of an effective winter navigation plan is to control ice to maintain winter navigation as long as possible using structural, operational and water management methods. This plan must also indicate when a project can no longer manage ice and navigation should stop. This winter navigation management plan should be considered for integrating into the water control plan for the total waterway system.

2-4. Hydroelectric Power

a. Historical Background. Hydroelectric power is a major element of many water resource projects developed by the Corps of Engineers. Major construction of hydroelectric facilities by the Corps began with the Federal development of the Tennessee River in 1918. Full-fledged national involvement in hydropower facilities by the Corps began in the 1930's as part of the national program for comprehensive water resource development. This role was expanded after the end of World War II, with many major power plants constructed in the Pacific Northwest, Midwest, and southern portions of the United States. Geographically, about 65 percent of the capacity is located in the Columbia River Basin in the Pacific Northwest; 9 percent is located in the Missouri River Basin; 15

percent in the lower Mississippi River Basin in the south-central United States; and about 10 percent is in the Southeast. This comparison indicates that the importance of hydropower varies widely from region to region, depending primarily upon the potential for developing this resource and alternative energy sources.

b. Hydropower Evaluation. The methods for evaluating hydropower capabilities, justification, power values, and power system operation are contained in EM 1110-2-1701. The reader is referred to that publication for details on hydropower systems and the planned use of water for producing electrical energy.

c. Types of Projects

(1) Dam and reservoir projects which incorporate hydropower generally fall into two distinct categories: (a) storage reservoirs which have sufficient capacity to regulate streamflows on a seasonal basis and (b) run-of-river projects where storage capacity is minor relative to the volume of flow.

(2) The storage projects are usually multipurpose, with water requirements for flood control, irrigation, navigation, municipal and industrial water supply use, fish and wildlife, recreation as well as hydropower. Normally, the upstream reservoirs include provisions for power production at the site, as well as for release of water for downstream control. Run-of-river hydropower plants are usually developed in connection with navigation projects.

(3) In addition, power facilities may be developed in off-stream water supply channels or irrigation works. In high mountain areas, off-stream diversions may be used for high-head power plants. These are likely to be single purpose projects. Also, "pumped storage" plants may be developed to utilize off-peak energy in an electrical, which is less costly, for pumping water to a storage reservoir in times of surplus energy and then releasing the water from storage to help meet peak system power demands. Under certain conditions hydropower could be developed from tidal fluctuations in bays or estuaries, but this has not yet been accomplished in the United States.

d. Integration and Control of Federal Hydropower Systems

(1) Integration and control of a major power system involving hydropower resources is generally accomplished by a centralized power dispatching facility. This facility contains the equipment to monitor the entire power system operation, including individual plant generation, substation operation, transmission line operation, power loads and requirements by individual utilities and other bulk power

users and all factors related to the electrical system control for moment-to-moment operation. The dispatching center is manned on a continuous basis, and operators monitor and control the flow of power through the system, rectify outages, and perform all the necessary steps to assure the continuity of power system operation in meeting system loads.

(2) Regulation and management of hydropower systems involve two levels of control, scheduling and dispatching. The scheduling function is performed by schedulers who analyze daily requirements for meeting power loads and resources and all other project requirements. Schedules are prepared and thoroughly coordinated to meet water and power requirements of the system as a whole. Projections of system regulation, which indicate the expected physical operation of individual plants and the system as a whole, are prepared for one to five days in advance. These projections are updated on a daily or more frequent basis to reflect the continuously changing conditions of power and water requirements.

e. Non-Federal Development of Hydropower at Corps of Engineers Projects

(1) The Federal Power Act as amended on 1 April 1975 delegates to the Secretary of the Army and to the Commander, USACE certain functions necessary for the Federal Energy Regulatory Commissions's (FERC) administration of the Act. ER 1110-2-1454 provides policy and guidance for review of preliminary permit and license applications for non-federal development at or affecting Corps projects.

(2) The Corps fully supports installation of hydropower by non-federal entities at Corps' projects, through FERC licensing procedures, so long as this renewable resource is developed in a systematic manner consistent with other authorized functions of these public projects and provided the addition of hydropower does not impact on the safety and integrity of existing Corps' structures. As a general policy compatible with the Federal Power Act, development of non-federal hydropower at the Corps' projects requires that total power potential of a site be considered. This potential can be developed in stages as the local and regional demand for electric power indicates. However, the first stage design and construction should include provisions for future expansion of power facilities compatible with the total power potential at a site and other project uses.

(3) In the interest of hydropower operation compatible with other authorized functions of the Federal project, FERC, upon recommendation by the Corps, will require the licensee to enter into a Memorandum of Agreement with the Corps describing the mode of

hydropower operation acceptable to the Corps. The FERC Regional Engineer shall be a party to these decisions. This Memorandum of Agreement shall be subject to revision by mutual consent of the Corps and licensee as experience is gained by actual project operation. The Memorandum of Agreement should be negotiated between the Corps District Commander, FERC Regional Engineer and the licensee. The negotiated agreement should be forwarded to the Corps Division Commander for approval. Upon approval by Corps Division Commander, the document will be transmitted to the FERC Regional Engineer and the licensee for concurrence and a request that tracings of the agreement be signed and returned to the Corps Division Commander. The original signed agreement along with the Plan of Regulation shall be kept on file in HQUSACE, Washington, D.C. Signed copies of the agreement will be provided to each party.

2-5. Water Supply

a. Irrigation

(1) Historical Background

(a) In the arid and semi-arid regions of the western United States, the use of water for irrigating arable lands has been a major factor in developing water resource systems. The seasonal nature of precipitation and the lack of rainfall in the growing season led to the development of agricultural water supplies following the turn of the century. Initially these projects were instituted on a local basis by individuals, but as the size and complexity of the developments increased, it became necessary to institutionalize these arrangements. This originated first at the local and state levels of government, but federal action was initiated by the Carey Act of 1894. Subsequently, the United States Reclamation Act of 1902 provided the means for federal involvement in planning and developing reclamation projects on both privately and federally owned agricultural lands. In principle, the act provided for interest-free loans for the construction of local irrigation projects.

(b) Initially, development of irrigation projects using surface water depended upon diversions from the natural flow of the rivers. As the developments increased in size, reservoirs were constructed to increase the dependable flow of the rivers, thereby assuring water supplies on an annual or multiyear basis when the natural flow was insufficient to meet demands. Initially, the reservoirs were constructed as single purpose developments for supplying water only for irrigation, but later multipurpose developments were conceived which better utilized the water resources available. Section 8 of the Flood Control Act of 1944 provided that Corps reservoirs may include irrigation as a purpose in 17 western states.

(2) Water Duty. The amount of water required to meet the demands for growing crops for the entire season is termed the water duty. This is equal to the total amount of water supplied to the land by means of gravity diversions from rivers or reservoirs or pumped from rivers, reservoirs, or underground sources of water. Net duty is the amount of water delivered to individual farm units, considering losses in canals, laterals, and waste from the point of diversion to the point of application on the land. In the western United States, the water duty ranges from about 1 to as much as 7 acre-feet per acre annually.

(3) Water Diversion Requirements and Return Flows

(a) Irrigation water diverted from reservoirs, diversion dams, or natural river channels is controlled in a manner to supply water for the irrigation system as necessary to meet the water duty requirements. The requirements vary seasonally, and in most irrigated areas in the western United States, the agricultural growing season begins in the spring months of April or May. The diversion requirements gradually increase as the summer progresses, reaching their maximum amounts in July or August. They then recede to relatively low amounts by late summer. By the end of the growing season, irrigation diversions are terminated, except for minor amounts of water that may be necessary for domestic use, stock water, or other purposes.

(b) The return flow of water from irrigated lands is collected in drainage channels, where it flows back into creeks and natural river channels. This return flow augments the prevailing river flow, and, depending primarily on quality, the return flow may be "re-used" for downstream irrigation or to supply some other water use function. The amount of return flow averages about 50 percent of the water diverted for irrigation purposes, but it may vary from about 20 to 70 percent.

(4) Reservoir Regulation for Irrigation

(a) Corps of Engineers reservoir projects have been authorized and constructed primarily for flood control, navigation, and hydroelectric power. However, several major Corps of Engineers multipurpose reservoir projects west of the Mississippi River include irrigation as a project purpose. Usually, water for irrigation is supplied from reservoir storage to augment the natural streamflows as required to meet irrigation demands in downstream areas. In some cases water is diverted from the reservoir by gravity through outlet facilities at the dam which feed directly into irrigation canals. At some of the run-of-river power or navigation projects, water is pumped directly from the reservoir for irrigation purposes.

(b) The general mode for regulation of water supply reservoirs to meet irrigation demands is to capture all runoff in excess of minimum flow demands during the spring and early summer. This usually results in refill of the reservoirs prior to the irrigation demand season. The water is held in storage until the natural flow recedes to the point where it is no longer of sufficient quantity to meet all demands for downstream irrigation. At that time, the release of stored water from reservoirs is begun and continued on a demand basis until the end of the growing season (usually September or October). During the winter, projects release water as required for instream flows, stock water, or other project purposes.

b. Municipal and Industrial Water Supply Use

(1) Basic Requirements

(a) Many Corps of Engineers reservoir projects supply water for municipal and industrial use (commonly termed M&I) as an authorized function. For those projects, the requirements constitute a firm commitment for reservoir storage to be used as a source of water supply to meet stated demands. For projects where M&I is an authorized function, the costs and benefits related to construction, operation, and maintenance are shared by local water users with other project functions, in accordance with long-term contractual agreements. In some projects, M&I water may be withdrawn from reservoirs under contractual arrangements that do not involve a commitment for the "use of the reservoir storage space". These withdrawals are considered to be from natural flow or from water in excess of the needs for other project functions.

(b) Chapter 7 of ER 1105-2-20 defines the objectives, policies, rights to storage, repayments, contractual requirements, and other aspects of plan formulation involved in incorporating water supply for M&I use into Corps of Engineers reservoirs. The policies stem largely from Sections 310(a) and (b) of the Water Supply Act of 1958. ER 1105-2-20 recognizes three general classifications of the use of M&I water supply from Corps of Engineers reservoirs: (a) Permanent Rights to Storage, which may be obtained by local interests under Public Law 88-140, through water supply contracts for use of specific amounts of reservoir storage space; (b) Surplus Water (i.e., water surplus to that required to fulfill the needs of authorized project purposes), for which Section 6 of the Flood Control Act of 1944 establishes the basis for non-Federal interests to make annual payments to cover proportional costs for operation, maintenance and replacement; and (c) Water Withdrawal, which may be obtained by local users pursuant to provisions of 31 U.S.C. 483a, by a contractual agreement which permits the user to construct, operate and maintain facilities for withdrawing water from the project.

(2) Water Management Problems

(a) Regulation of reservoirs for M&I water supply is performed in accordance with contractual arrangements. Storage rights of the user are defined in terms of acre-feet of stored water and/or the use of storage space between fixed limits of reservoir levels. The amount of storage space is adjusted to account for change in the total reservoir capacity that is caused by sediment deposits. The user has the right to withdraw water from the lake or to order releases to be made through the outlet works. This is subject to certain rights reserved for the government with regard to overall regulation of the project and to the extent of available storage space.

(b) In times of drought, special considerations may guide the regulation of projects with regard to water supply. ER 1110-2-1941 provides policy and guidance for the preparation of drought contingency plans. Adequate authority to permit temporary withdrawal of water from Corps projects is contained in 31 U.S.C. 483a. Such withdrawal requires a fee that is sufficient to recapture lost project revenues, and a proportionate share of operation, maintenance and major replacement expenses.

2-6. Water Quality

a. Management Requirements. Water quality encompasses the physical, chemical, and biological characteristics of water and the abiotic and biotic interrelationships. The quality of the water and the aquatic environment is significantly affected by management practices employed by the water control manager. The effects of improper management are often far-reaching and long-term; may range from minor to catastrophic; and may be as obvious as a fish kill or subtle and unnoticed. It is essential that all water control management activity and especially real-time actions include valid water quality evaluations as a part of the daily water control decision process. It must be understood that water quality benefits accumulate slowly, build on each other and can become quite substantial over time. This is in contrast to the sudden flurry of benefits that can come from a flood control operation. Typically, projects built for flood control operate for flood management only 2 to 3 percent of the time and must operate for water quality to some degree all of the time. Water quality benefits can be accrued only by integrating on a continuous basis the input of individuals with a basic knowledge and understanding of water quality, biological, chemical and physical factors as they are related to the reservoir/river environment. This is the single most important aspect of water control management for water quality; therefore, it is essential that the water control management team have members who are expert in these subjects. The linkage between the water control and water quality groups should be very close, and it is preferable that both functions reside in the same organizational element. Of near equal importance is first hand knowledge of the projects and the streams influencing and influenced by the projects.

b. Objectives and Water Quality Standards

(1) Water quality control is an authorized purpose at many Corps of Engineers reservoirs. However, even if not an authorized project purpose, water quality is an integral consideration during all phases of a project's life, from planning through operation. This Corps policy is based on Section 313 of the Clean Water Act of 1979 and Executive Order 12088, 13 October 1978, both of which require Federal compliance with applicable pollution control standards that apply to any private entity. The goal is to, as a minimum, meet State and Federal water quality standards in effect for the lakes and tailwaters. The operating objective is to maximize beneficial uses of the resource through enhancement and nondegradation of water quality. Attaining that goal requires continuous efforts at managing water quality by developing programs and objectives and performing the necessary studies, data collection, analysis, coordination, and real-time management.

(2) Water quality management objectives for new projects are defined early in the planning phase in accordance with ER 1110-2-1402. Programs to meet the objectives are subsequently developed and implemented by the start of operation of the project at the latest. ER 1130-2-415 contains guidance on the collection, interpretation and application of water quality data within the framework of the overall management program. Guidance on establishing Division-wide water quality management programs and requirements for reporting of associated water quality management activities is contained in ER 1130-2-334.

c. Monitoring Water Quality Conditions. Knowledge of water quality conditions is essential for effective water control management and therefore, continual water quality monitoring efforts are required. Data collection programs will be tailored to each project, the intent being to insure that project purposes and uses are not compromised and to monitor the effects of project regulation on lake and tailwater quality. Additionally, known or suspected problems such as nuisance algae or priority contaminants, require special and often more intensive data collection efforts. Guidance on data collection and reporting requirements are contained in ER 1130-2-415 and ER 1130-2-334. A comprehensive treatment of all aspects of water quality monitoring and data analysis can be found in EM 1110-2-1201.

d. Water Quality Releases for Downstream Control. Water quality releases for downstream control have both quantitative and qualitative requirements. The quality aspects relate to Corps policy and objectives to meet state water quality standards, maintain present water quality where standards are exceeded and maintain an acceptable tailwater habitat for aquatic life. The Corps has responsibility for the quality of water discharged from its projects. One of the most important measures of quality is quantity. At many projects authorized for water quality control, a minimum flow at some downstream control point is the water quality objective. An appropriate level of data collection is required for project operation to insure attainment of water quality requirements through reservoir regulation activities. Coordination between water quality and water control personnel and integration of water quality into water control management procedures are essential and must be described in project water control manuals as prescribed in ETL 1110-2-251, Preparation of Water Control Manuals.

e. Selective Withdrawal Facilities for Water Quality Control

(1) Most impoundments exhibit some degree of temperature stratification. In general, deeper lakes are more likely to become highly stratified each summer and are not likely to become mixed by wind or short-term temperature changes. When the surface of the lake begins to receive a greater amount of heat from the sun and air than is lost, it becomes warmer and less dense, while the colder, more dense water remains on the bottom. In the layer of colder water near the bottom, little if any oxygen is transferred from the air to replace that depleted by oxidation of organic substances, and, eventually, anoxia may develop. Under this condition, a reducing environment is created, resulting in elevated levels of parameters such as iron, manganese, ammonia and hydrogen sulfide. Changes such as these may result in water that is degraded and toxic to aquatic life.

(2) Due to the great vertical variation in water quality, the primary means of managing the water quality of reservoir releases is to provide facilities for withdrawing water from various levels in the lake. This is accomplished by the use of intake structures with multilevel withdrawal capability. These intake facilities should be designed in accordance with ER 1110-2-1402. Project releases should

meet the desired temperature and dissolved oxygen content and other water quality criteria as nearly as possible. Establishment of these criteria is prescribed in the referenced ER 1110-2-1402. The vertical profile may be such that all criteria may not be satisfied by withdrawing from any one elevation. For example, it may be necessary to draw cold water from a lower level, where oxygen is deficient, in combination with water from a higher, warm layer to supply the required oxygen. Because of the uncertainty involved with proportioning flow through two or more intakes in a single wet well, it may be necessary to provide dual wet wells as part of the selective withdrawal facilities.

(3) Selective withdrawal structures also provide an opportunity for managing the in-lake environment. This can be accomplished by selectively withdrawing and blending good and poor quality water when the resulting product will meet the release objective. This type of integrated management will help to prevent an overloading of low quality water in the lake which could lead to a collapse of both tailwater and reservoir quality.

(4) Much research has been undertaken to address operational aspects of water quality control, such as where profiles in the lake should be taken, the withdrawal characteristics of intakes under different flow conditions, blending of flows in single wet wells, where to measure the discharge quality, etc. Detailed technical guidance is given in EM 1110-2-1201, and assistance in these matters may be obtained from the Committee on Water Quality as outlined in ER 15-2-14.

f. Water Quality System Regulation

(1) Coordinated regulation of multiple reservoirs in a river basin is required to maximize benefits beyond those achievable with individual project regulation. System regulation for quantitative aspects, such as flood control and hydropower generation, is a widely accepted and established practice, and the same principle applies to water quality concerns. Water quality maintenance and enhancement beyond the discernible effects of a single project are possible through coordinated system regulation. This applies to all facets of quality from the readily visible quantity aspect to traditional concerns such as temperature and dissolved oxygen.

(2) System regulation for water quality is of most value during low flow periods when available water must be used with greatest efficiency to avoid degrading lake or river quality. Water control decisions are formulated based on current and forecasted basin hydrologic, meteorologic and quality conditions, reservoir status, quality objectives and knowledge of water quality characteristics of

component parts of the system. Required flows and qualities are then apportioned to the individual projects resulting in a quantitatively and qualitatively balanced system. Computer programs capable of simulating reservoir system regulation for water quality provide useful tools for deriving and evaluating water control alternatives.

2-7. Fish and Wildlife

a. Historical Background. The Fish and Wildlife Coordination Act of 1958 as amended, provides that fish and wildlife receive equal consideration with other project purposes and be coordinated with other features of water resource development programs. The water resource construction agencies are to consult with fish and wildlife agencies on justifiable means and measures for fish and wildlife enhancement. The Corps may recommend project modifications and acquisition of lands for fish and wildlife conservation purposes. Section 2(a) of the Act defines the area of interest to include impoundment, diversion, channel deepening, or any modification of a stream or other body of water. Section 2(b) of the Act specifies that the project plan shall include such justification means and measures for wildlife purposes (mitigation and enhancement) as the reporting agency finds should be adopted to obtain maximum overall project benefits. Therefore, prevention of damages to fish and wildlife resources must be provided to the extent practicable, not only by planning and design, but by good water management practices as well.

b. General

(1) Fish and wildlife management opportunities and problems related to water control vary widely depending upon geographical location, the management objectives and the operational capabilities of the project. The project water quality characteristics discussed previously, as well as the ability to manipulate these conditions, greatly influence reservoir fisheries and the ability to meet fish and wildlife management objectives.

(2) Most large water control projects are authorized and designed for multiple purposes and must be operated within the constraints of these purposes. However, authorized project purposes usually contain enough flexibility to permit some manipulation of water levels and reservoir releases for fisheries management and other wildlife considerations. Water control managers should take the initiative to evaluate opportunities for managing fish and wildlife habitats, by continually evaluating the effects of project regulation. This includes being aware of pool level fluctuations,

the quality, quantity and timing of project releases and the associated impact on the fish and wildlife.

(3) Developing guidance for creatively managing water control projects for fisheries is complicated by the wide range of hydrometeorological events that may occur, as well as the effects of regulation for the individual projects authorized purposes. Further complexity is introduced because habitat requirements for spawning, incubation and emergence times vary greatly among species.

(4) While the structural design of the project may limit the flexibility of regulation strategies, water control managers are tasked with the challenge of trying to meet fishery management objectives. Because of their understanding of the projects' water quality characteristics and resulting effects on reservoir or downstream fisheries, the water control manager can be in a unique position to recommend evaluation of structural modifications, possible reallocations of project storage, or modifications to regulating plans. Prior to undertaking any of these actions, the objectives and priorities for fish and wildlife management should be identified and coordinated with appropriate fish and natural resource agencies. This may include state fish and wildlife agencies, the U.S. Fish and Wildlife Service, the National Marine Fishery Service and Indian tribes. Coordination of these actions provides more effective oversight of fish and wildlife in relation to other uses of the basin, and draws upon existing experience and expertise.

c. Reservoir Fisheries

(1) Project regulation can influence fisheries both in the pool and downstream. One of the most readily observable influences of reservoir regulation is reservoir pool fluctuations. Periodic fluctuations in reservoir water levels present both problems and opportunities to the water control manager with regard to fishery management. The seasonal fluctuation that occurs at many flood control reservoirs, and the daily fluctuations that occur with hydropower operation often result in elimination of shoreline vegetation and subsequent shoreline erosion, water quality degradation and loss of habitat. Adverse impacts of water level fluctuations also include loss of shoreline shelter and physical disruption of spawning and nests.

(2) Some of the fishery management techniques that may be implemented include: pool level management for weed control; forcing forage fish out of shallow cover areas, making them more susceptible to predation; maintaining appropriate pool levels during spawning; decreased wide fluctuations in pool levels. The lowering of levels during spawning is sometimes also combined with rough fish removal

during drawdown to help manage for another, more desirable fishery. Wave action from slowly draining the water down can help maintain clean gravel substrates, which are favorable to some target fish species.

(3) The success of each management technique varies from region to region, and lake to lake. This variability in physical, biological, chemical and operational characteristics in addition to uncontrolled environmental influences, makes predicting the results of changes in reservoir levels and releases for fishery management difficult. Reservoir design, mode of operation, and specific life history requirements of target fishes play primary roles in determining water management strategies. Manipulation of water levels to enhance fisheries is often based on the timeliness of flooding or dewatering shoreline vegetation. Where seasonal flooding of shoreline vegetation is recommended, fishery management plans may include lowering water levels during a portion of the growing season to permit regrowth of vegetation. By regulating the timing and duration of flooding, water level management schemes can be developed for a particular reservoir which encourage the establishment of desirable innocuous macrophytes and reduce nuisance aquatic plants.

(4) A great deal of information is available to water control managers to assist them in tailoring shore vegetation management programs to their specific projects and needs. This includes information on the identification of plant species suitable for shoreline revegetation and information to determine the feasibility of revegetation at a specific project (EP 1110-1-3). In addition to stabilizing the soil, which in turn improves water quality, shoreline vegetation provides nursery grounds and cover for fish and their food organisms, food for birds and terrestrial wildlife.

(5) Water-level management in fluctuating warm-water and cool-water reservoirs generally involves raising water levels during the spring to enhance spawning and survival of young predators. Pool levels are lowered during the summer to permit regrowth of vegetation in the fluctuation zone. Fluctuations may be timed to benefit one or more target species; therefore, several variations in operation may be desirable. In the central United States, managers frequently recommend small increases in pool levels during the autumn for waterfowl management.

(6) Fall and winter drawdown is often recommended for shallow reservoirs that support large stands of water plants (aquatic macrophytes). The method is effective in concentrating prey species and controlling aquatic vegetation. Drawdowns that reduce surface area by as much as 50 percent may be desirable. As with other basic

approaches to water-level management, numerous variation have been applied.

(7) In addition to actions to achieve small pool fluctuations, periodic major drawdown has been used effectively for fishery management. This procedure involves drastic lowering of a reservoir pool level over an extended time period (at least one growing season) to permit vegetative regrowth in the dewatered zone. This may be augmented by seeding of plants to establish desirable species. Some objectives may be accomplished by selectively removing or killing various fish communities. After this, the reservoir is refilled during the spring, fish are restocked, and a high water level maintained through the summer. This technique is effective for stimulating production of desirable sport and prey fishes, but if it conflicts with authorized reservoir purposes, it may be difficult to implement.

(8) Water-level management in cold-water reservoirs has been mostly oriented toward the production and enhancement of salmonoids, with anadromous species receiving primary consideration. Important management problems relating to production of salmonoids include maintaining access to tributary streams for spawning, controlling releases to facilitate passage of anadromous species, limiting losses of important sport fishes, and stabilizing reservoir pool levels during the extended periods of egg and larval development of certain species.

d. <u>Tailwater Fisheries</u>

(1) Guidelines to meet downstream fishery management potentials should be developed for each project based on project water quality characteristics and the water control capabilities. To do so, an understanding of the reservoir water quality regimes is critical for developing the water control criteria to meet the objectives. For example, temperature is often one of the major constraints of fishery management in the downstream reach, and water control managers must understand the temperature regime in the pool and downstream temperature requirements, as well as the capability of the project to achieve the balance required between the inflows and the releases. Releasing cold-water downstream where fishery management objectives require warm water will be detrimental to the downstream fishery. Conversely, releasing warm water creates difficulty in maintaining a cold-water fishery downstream.

(2) Water control activities can also impact water temperatures within the pool by changing the volume of water available for a particular layer. In some instances, cold-water reserves may be necessary to maintain a downstream temperature objective in the late

summer months and therefore, the availability of cold water must be maintained to meet this objective. For some projects, particularly in the southern US, water control objectives include the maintenance of warm-water sports fisheries in the pool, and in some cases, cold-water fisheries in the tailwaters. In other instances, fishery management objectives may include the maintenance of a two-story fishery in a reservoir, with a warm-water fishery in the surface water, and a cold-water fishery in the bottom waters. Such an objective challenges water control managers to regulate the project to maintain the desired temperature stratification while maintaining sufficient dissolved oxygen in the bottom waters for the cold-water fishery. Regulation to meet this objective requires an understanding of operational effects on seasonal patterns of thermal stratification, and the ability to anticipate thermal characteristics.

(3) Minimum instantaneous flows can be beneficial for maintaining gravel beds downstream for species that require this habitat. However, dramatic changes in release volumes, such as those that result from flood control regulation, as well as hydropower, can be detrimental to downstream fisheries. Peaking hydropower operations can result in releases from near zero to very high magnitudes during operations at full capacity. Maintaining minimum releases and incorporating reregulation structures are two of the options available to mitigate this problem.

(4) In some instances tailwater fishing is at a maximum during summer weekends and holidays and this is a time when power generation may be at a minimum and release near zero. Maintaining a minimum releases during weekend daylight hours may improve the recreational fishing, but may reduce the capability to meet peak power loads during the week because of lower water level (head) in the reservoir. In this instance, water control managers will be challenged to regulate the project with consideration of these two objectives.

(5) Opportunities for modification of reservoir regulation increase with the complexity of the reservoir river system, (e.g., Columbia, Missouri, Lower Ohio River Basins) where reservoir regulation is highly integrated. Reservoirs regulated primarily for flood control generally provide greater flexibility for water level management than hydropower projects.

e. Fish Migration

(1) Another concern, particularly in the Pacific northwest, is the maintenance of successful migration of anadronomous fish, such as salmon; similar objectives exist in the northeastern U.S. and in places where other anadromous fish such as striped bass, have become

established. Declines in anadronomous fish populations have been attributed to dams due to: blockage of migration, alteration of normal stream flow patterns, habitat modification due to inundation, blockage of access to spawning and rearing areas, delays in migration rates and changes in water quality.

(2) Regulation for anadromous fish is particularly important during certain periods of the year. Generally, upstream migration of adult anadromous fish begins in the spring of each year and continues through early fall, and downstream migration of juvenile fish occurs predominantly during the spring and summer months. The reduced water velocities through reservoirs in comparison with preproject conditions, may greatly lengthen the travel time for juvenile fish downstream through the impounded reach. In addition, storage for hydropower reduces the quantity of spill, and as a result, juvenile fish must pass through the turbines. The delay in travel time subjects the juvenile fish to greater exposure to birds and predator fish, and passage through the powerhouse turbines increases mortality. To improve juvenile survival, storage has been made available at some projects to augment river flows, and flows are diverted away from the turbine intakes and through tailraces where the fish are collected for transportation or released back into the river. Barges or tank truck can be used to transport juveniles from the collector dams to release sites below the projects. Other Corps projects have been modified so the ice and trash spillways can be operated to provide juvenile fish passage.

(3) Regulation for adult fish passage may include selective operation of power units and spillway bays to control downstream flow patterns in a manner necessary to attract adult fish to ladder entrances. Additional information pertaining to the use of water control facilities to protect and enhance anadronomous fisheries is included in Chapter 4.

f. Minimum Releases. The Corps is also responsible for providing established minimum releases from water control projects for maintenance of downstream fisheries and the overall downstream aquatic environment. The release influences the downstream food supply, water velocity and depth. Water control managers must often maintain minimum releases for this purpose along with minimum flow requirements for other instream requirements.

g. Reservoir Wildlife

(1) Project regulation can influence wildlife habitat and management principally through water level fluctuations. These fluctuations present both problems and opportunities to the water control manager relative to wildlife habitat and its management.

(2) The beneficial aspects of periodic drawdowns on wildlife habitat are well documented in wildlife literature. Drawdowns as a wildlife management technique can, as examples, allow the natural and artificial revegetation of shallows for waterfowl; permit the installation and maintenance of artificial nesting structures; allow the control of vegetation species composition; and ensure mast tree survival in greentree reservoirs. Wildlife benefits of periodic flooding include inhibiting the growth of undesirable and perennial plants; creating access and foraging opportunities for waterfowl in areas such as greentree reservoirs; and ensuring certain water levels in stands of vegetation to encourage waterfowl nesting and reproduction.

(3) Water level manipulations conducted without regard to effects on wildlife habitat can result in many adverse impacts. Such impacts include the destruction of emergent and terrestrial vegetation; permitting predator access to otherwise inaccessible areas, such as during drawdowns; abandonment of active nest sites; and rendering soils with iron oxides unproductive when dried out.

2-8. Recreation

a. Historical Background. The use of reservoir projects for recreational purposes stems from the Flood Control Act of 1944 and the Federal Water Project Recreation Act of 1965 (PL 89-72). The Federal interest in the provision of recreation opportunities at Corps of Engineers projects is limited; that is, other project purposes, such as flood control or navigation, are needed to establish Corps interest. Many projects, including those for which recreation facilities may have been included under general provisions of the Flood Control Act of 1944, as amended, do not have separable storage costs for recreation. While under these circumstances recreation is an authorized purpose, it is secondary to project functions for which the storage was formulated. Any reallocation of reservoir storage that would have a significant effect on authorized purposes or that would involve major structural or operational changes requires Congressional approval.

b. General Requirements. The general public uses reservoirs for water-related recreational activities. Also, river systems below dams are frequently used for recreational boating, swimming, fishing, and other water related activities. Regulation of project outflows must consider the effects of streamflows and water levels on these activities at the project site, in the reservoir area, and in the rivers at downstream locations. Reservoir regulation criteria include special considerations for these purposes.

c. Water Management Problems

(1) Recreational use of the reservoirs may extend throughout the entire year. Under most circumstances, the optimum recreational use of reservoirs would require that the reservoir levels be at or near full conservation pool during the recreation season. The degree to which this objective can be met varies widely, depending upon the regional characteristics of water supply, runoff, and the basic objectives of water regulation for the various water use functions. Facilities constructed to enhance the recreational use of reservoirs may be designed to be operable under the planned reservoir regulation guide curves on water control diagrams, which reflect the ranges of reservoir levels that are to be expected during the recreational season.

(2) In addition to the seasonal regulation of reservoir levels for recreation, regulation of project outflows may encompass requirements for specific regulation criteria to enhance the use of the rivers downstream from the projects, as well as to insure the safety of the general public.

d. Long-Term Seasonal Fluctuations of Reservoirs. In the West, normal flood control, navigation, or power regulation may meet recreational requirements since seasonal regulation normally permits refill of the storage space to normal full conservation pool during spring or early summer. In low runoff years, or years in which the runoff is delayed because of weather conditions, it may be impractical to meet the desired needs for full pool reservoir levels during the recreation season.

e. Control of Streamflows for Downstream Recreational Use. The Corps has the responsibility to regulate projects in a manner to maintain or enhance the recreational use of the rivers below projects to the extent possible. In the peak recreation season, streamflows should be well regulated to insure the safety of the public who may be engaged in water related activities, including boating, swimming, fishing, rafting, river drifting, etc. Also, the aesthetics of the rivers may be enhanced by augmenting streamflows in the low water period. Water requirements for maintaining or enhancing the recreational use of rivers are usually much smaller than other major project functional uses. Nevertheless, it is desirable to include specific goals to enhance recreation in downstream rivers in the water control plan. The goals may be minimum project outflows or augmented streamflows at times of special need for boating or fishing. Of special importance is minimizing any danger that might result from changing conditions of outflows which would cause unexpected rise or fall in river levels. Also, river drifting is becoming an important recreational use of rivers, and in some cases it may be possible to enhance the conditions of streamflow for relatively short periods of time for this purpose.

2-9 Erosion and Deposition Considerations

a. General. Natural stream erosion and deposition processes are significantly altered through the construction and operation of dams. The impacts of individual projects vary significantly, depending on the streamflow and sediment characteristics of the parent stream, and the specific operating rules of a given project. Interruption of the natural sediment processes of a stream generally results in deposition of sediment in the upstream reservoir area, and corresponding erosion and degradation of the streambed and banks immediately downstream from the project. The location of deposits in the reservoir is a function of the size of the reservoir, the size and magnitude of the sediments being transported, and the pool level at the time of significant inflow. The amount of bank and shoreline erosion is closely related to the rate and magnitude of the pool level fluctuations. The entire erosion/deposition process impacts many project related functions, and must be recognized, considered, and carefully monitored throughout the life of a project.

b. Downstream Considerations

(1) Large reservoir projects frequently trap and retain all of the suspended sediment and bed material load within the upstream pool, thus releasing sediment-free water. These releases, often varying from zero to maximum capacity within a very short time frame are capable of eroding both the banks and bed of the stream immediately downstream from the outlet structure resulting in a permanent loss of valley lands. The amount and rate of this erosion is related to the composition of the bed and bank material, the volume of water released on an annual or seasonal basis, the rate of these releases, and the manner in which the flow is released. Fluctuating releases often result in an initial loss of the banks, and this loss is closely related to the magnitude of the expected stage fluctuation. The recession of banks due to fluctuating releases usually stabilizes in the first few years of operation, as the underwater slope reaches a quasi state of equilibrium. Once this equilibrium slope has been achieved, the bank erosion process behaves as in the natural channel. Periodic wetting and drying of the banks through fluctuating releases accelerates this process. Reservoir releases also result in lowering of the streambed, with the maximum amount of lowering occurring immediately downstream from the outlet works, and decreasing in the downstream direction. This degradation process continues until the slope is reduced to its equilibrium value

and/or the bed becomes naturally armored by removal of the fines, which exposes the coarser, non-erodible bed materials. Once the bed becomes naturally armored, future lowering of the streambed is usually insignificant.

(2) Channels downstream from small and medium size projects often exhibit entirely different characteristics than described above, and tend to lose their channel capacity over time. Projects that make only intermittent releases over short periods of time, or low level releases over extended periods of time are candidates for extensive deposition and subsequent vegetative encroachment. This process tends to build upon itself, and once established is difficult to reverse. The once-annual flushing flows capable of removing deposits near the mouth of tributaries are often replaced by low level non-erosive releases, thus contributing to the loss of channel capacity and future operating flexibility.

c. Upstream Considerations

(1) Shoreline Erosion. Reservoir shorelines are subject to a number of forces contributing to their instability, and frequently undergo major changes throughout the life of a project. Fluctuating pool levels saturate previously unsaturated material, resulting in massive slides when the pool level is drawn down to lower levels. This material accumulates at the base of the slope, and often forms an underwater bench, leaving steep unstable slopes above the water line. Reservoir banks are also subjected to attack by both wind and waves, which tend to remove this material and undercut the banks. Protection against these forces can be a very costly endeavor, and must often be limited to specific areas of concern. Prediction of the amount and locations of severe bank erosion is an important long-term concern, as it impacts on such things as the amount of project lands that need to be purchased, location of recreation features, and general use of adjacent lands.

(2) Reservoir Deposition. Sediment deposits in the reservoir pool are an important consideration and concern, as they impact not only on the reservoir storage capacity over the life of the project, but also on many project purposes both adjacent to the pool and in the backwater reach immediately upstream from the pool. Sediment deposits are not restricted to the lower reservoir zone frequently reserved as a sediment pool, but often deposit in the multipurpose or flood control pool zones in the form of large deltas and cause a multitude of problems and concerns as the project matures. Major sediment deposits can reduce the storage reserved for flood control to such an extent that adjustment in the pool levels becomes necessary in order to maintain the flood storage capacity. The deposits also can have a significant impact on the backwater profile

of reservoir inflows over time, resulting in increased groundwater and surface water levels and flooding problems in the areas immediately upstream from the reservoir pool. The location of the sediment deposits can also affect and contribute to ice accumulations and jams which may become an operational constraint during certain times of the year. The impact of sediment accumulations in the reservoir, over the life of the project, should be recognized and accounted for in the overall planning and operation of the project.

d. Guidelines. Water control managers should be cognizant of the impacts of operating procedures on the erosion and deposition process, and should operate in such a manner to minimize both upstream and downstream adverse impacts. In order to accomplish this, it is necessary to be fully informed of all known problem areas, and the potential impact of alternative regulation decisions. Although much of the erosion/deposition process is beyond the control of the water manager, certain precautions can significantly minimize problems. These include:

- Minimize the rate of reservoir pool drawdown.

- Avoid sudden increases in project releases and subsequent downstream stage fluctuations.

- Avoid sudden cutbacks in powerplant or flood control releases and resultant stage fluctuations.

- Keep reservoir pool levels as low as possible during known periods of high sediment inflow, thus encouraging sediment to deposit in the lower zones of the pool.

- Periodically raise pool levels high enough to inundate existing sediment deposits, thus precluding the establishment of permanent vegetation and subsequent increased sediment deposits in the backwater reaches entering the pool.

- Schedule periodic releases through the outlet works to preclude sediment accumulations in and near the intake structure and in the downstream channel.

- Be aware of conditions that may impact on the erosion/deposition process, such as the potential for ice jams, tributary inflow, shifting channels, and local constraints, and adjust regulation criteria to minimize adverse impacts.

2-10. Aesthetic Considerations. The effects of reservoir regulation on the aesthetics of the river system are closely related to the public use of reservoirs and rivers and must be considered in the management of water control systems. Management of such systems may involve the mitigation of adverse effects related to the aesthetics and the general beauty of the riverine environment. Such mitigation may include establishing minimum streamflows and their related river levels, minimizing the duration of exposure of unsightly reservoir shoreline resulting from reservoir drawdown, or releasing water for special aesthetic purposes. For many water control projects, it may be virtually impossible to compensate fully for such effects and still maintain the integrity of the functions for which the projects were authorized and constructed. For some projects, adjusting water control plans to help mitigate these effects, even though they may be only a partial remedy, may be feasible. The relative importance of these considerations varies widely from case to case, and the solutions to problems involved in adjusting water control plans to meet the aesthetic goals require judgment and full knowledge of all water management functions.